NASA SPACE VEHICLE DESIGN CRITERIA

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FLUTTER, BUZZ, AND DIVERGENCE

VOLUME III: STRUCTURES

PART B: LOADS AND STRUCTURAL DYNAMICS

CHAPTER 1: GENERAL CRITERIA

SECTION 1: FLUTTER, BUZZ, AND DIVERGENCE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

FOREWORD

NASA experience has indicated a need for uniform design criteria for space vehicles. Accordingly, criteria are being developed in five areas of technology, outlined as follows:

Volume I — Environment
Volume II — Material Properties and Processes
Volume III — Structures
Volume IV — Stability, Guidance, and Control
Volume V — Chemical Propulsion

The individual components of this work are regarded as being sufficiently useful to justify publication separately in the form of monographs as completed. This document, Section 1 of Volume III, Part B, Chapter 1, is one such monograph. The planned general outline of Volume III is set forth on page ii.

These monographs are to be regarded as guides to design and not as design requirements, except as may be specified by NASA project managers or engineers in formal project specifications. It is expected, however, that these documents, revised as experience may indicate to be desirable, will eventually become uniform design requirements for NASA space vehicles.

Comments from addressees concerning the technical content of the monographs are solicited. Please address such comments to the National Aeronautics and Space Administration, Office of Advanced Research and Technology (Code RVA), Washington, D. C. 20546.

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PLANNED OUTLINE OF VOLUME III: STRUCTURES

Volume III: Structures
Part B: Loads and Structural Dynamics
Chapter 1: General Criteria

SECTION 1: FLUTTER, BUZZ, AND DIVERGENCE

1.1 INTRODUCTION

Flutter is a self-excited oscillation of a vehicle surface or component caused and maintained by the aerodynamic, inertia, and elastic forces in the system. For a given structural system there are combinations of Mach number and dynamic pressure which define a flutter boundary. At a given Mach number, flight at dynamic pressures below the flutter boundary will result in damped oscillations. At the flutter boundary a transition occurs so that for higher dynamic pressures, oscillations will be sustained at some limiting amplitude or will diverge until a structural failure occurs. In addition to being dependent on Mach number and dynamic pressure, the occurrence of flutter is dependent on such factors as structural stiffness, mass and mass distribution, stiffness changes due to steady and transient thermal inputs, control-surface actuation-system dynamics, system tolerances, misalinements, and free play.

Control-surface buzz is a type of flutter involving only one degree of freedom. It is usually a pure rotational oscillation of a control surface, but may appear as a torsional "windup" oscillation if the surface is restrained near one end. Buzz generally occurs in regions of transonic flow.

Divergence is a nonoscillatory instability which occurs when the restoring moments within a system are exceeded by the external aerodynamic moments. Divergence can be a critical design problem on some slender configurations. It is usually not a consideration for sweptback surfaces.

Panel flutter will be considered in a separate section.

1.2 STATE OF THE ART

The aeroelastic phenomena covered in this section have a long history of research. Techniques for analyzing structures for flutter and divergence are documented in references 1 to 9.

While methods of analyzing structures for flutter and divergence are available, the application of these methods in certain speed ranges produces questionable results. For example, the reliability of aeroelastic analyses in the transonic speed range is low owing to the lack of a suitable unsteady aerodynamic theory. Difficulties also arise in cases where the validity of available techniques has not been established (e.g., for surfaces of very low aspect ratio), in cases where aerodynamic heating is a significant factor, and at hypersonic speeds.

A flutter modeling technology which complements analytical techniques is discussed in reference 2. In the transonic speed range, such model tests are considered to provide the most reliable flutter information. However, the accuracy of model data is limited by inability to predict and duplicate exactly the structural characteristics and aerodynamic forces. Results of model tests which attempt to simulate aerodynamic heating effects are also questionable owing to difficulties in meeting scaling requirements, as discussed in references 10 and 11. These difficulties have meant that, in spite of the wide application of analysis and modeling techniques in designing to avoid flutter, flight tests generally have been required to provide the final proof of freedom from flutter within the operating flight envelope.

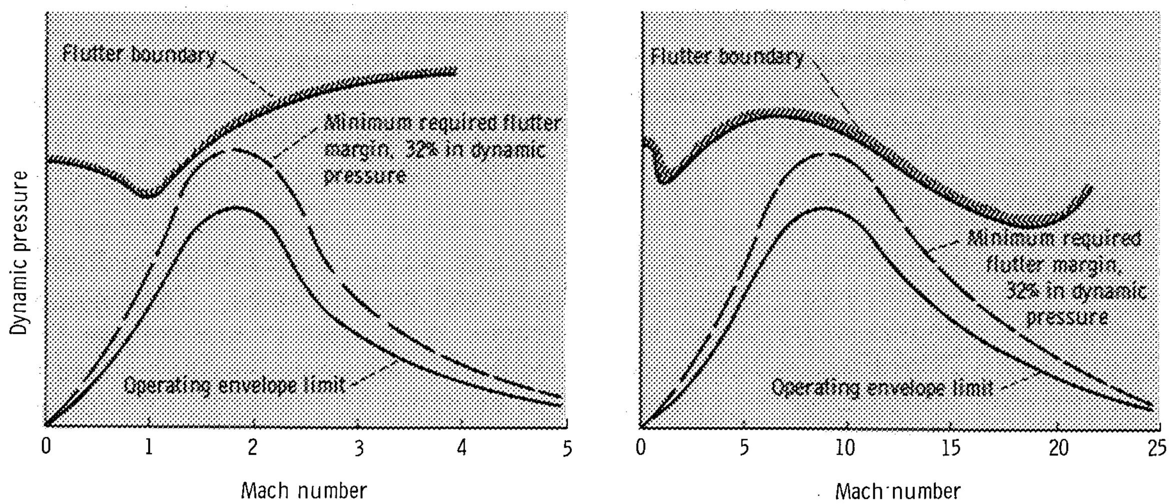
No satisfactory analytical method exists for predicting control-surface buzz. Reference 5 contains a summary of available information. Design techniques depend on empirical data to indicate marginal or dangerous situations, and wind-tunnel and flight tests are made to substantiate the design.

In general, the comments made in the foregoing paragraphs also apply to divergence, which is discussed in reference 4.

1.3 CRITERIA

Space vehicles shall be free of flutter, buzz, and divergence at dynamic pressures up to 1.32 times the maximum dynamic pressure expected to be encountered at any flight Mach number.[1] (See fig. 1.) The maximum dynamic pressure should be determined by considering expected variations in the natural environment and tolerances of vehicle system parameters. Expected variations in environment, combinations of environments, and system tolerances, once

[1]The factor 1.32 to be applied to dynamic pressure corresponds to the factor 1.15 applied to velocity in the design of aircraft (ref. 6).



(a) Launch and exit phase of flight.

(b) Entry phase of flight.

Figure 1.–Graphical representation of minimum required flutter margins.

determined, should be clearly indicated in applicable documentation. Both normal operating conditions and aborts from normal operating conditions should be considered in defining the limits of the dynamic-pressure envelope.

Analyses and tests should be conducted to demonstrate freedom from flutter and divergence and should include, but not be limited to, consideration of static and transient thermal effects, loading conditions, dynamics of the control-surface actuation system, system tolerances, misalinements, and free play.

Instrumentation for detecting flutter should be provided on at least one vehicle during development flight tests.

1.4 RECOMMENDED PRACTICES

1.4.1 ANALYSIS

Flutter and divergence analyses should include all significant degrees of freedom such as symmetric and antisymmetric bending, torsion, chord bending, rotation of lifting surfaces and control surfaces, and body bending and torsion. The preferred formulation of flutter analyses will utilize vibration modes and frequencies although a formulation using aerodynamic and structural influence coefficients is acceptable. Vibration modes can be either coupled modes or uncoupled or assumed modes. If uncoupled or assumed modes or an influence-coefficient approach is used, the coupled vibration modes and frequencies at zero airspeed should be calculated from the flutter equations for correlation with measured modes and frequencies.

A variety of methods is available for calculating stiffness and vibration characteristics of the structure. Beam-type analyses are adequate for surfaces with high aspect ratios ($A > 5$ or 6), but low-aspect-ratio surfaces require treatment as plates or built-up structures. Thermal effects should be considered in determining these stiffness or vibration characteristics. References 1, 2, and 8 and volume 1 of reference 5 contain discussions of the techniques that are acceptable.

The methods for calculating unsteady aerodynamic forces for flutter and divergence studies vary greatly with speed and configuration. Discussions of available techniques are found in references 2, 4, and 12 and volume 2 of reference 5. Two-dimensional aerodynamic coefficients can usually be used in a strip-theory analysis for high-aspect-ratio surfaces ($A > 5$ or 6). However, low-aspect-ratio surfaces require a three-dimensional or lifting-surface theory for adequate prediction of unsteady aerodynamic forces. At subsonic speeds, a lifting-surface theory such as the numerical method presented in reference 13 is recommended. At low supersonic speeds ($M < 2$ or 2.5), lifting-surface methods such as those described in references 14 and 15 are recommended. At higher supersonic speeds, piston theory, described in references 15 and 16, is acceptable. At hypersonic speeds, methods are not well established although there are indications (refs. 17 to 23) that Newtonian flow theory or piston theory may be applicable.

1.4.2 TESTS

Model tests or component tests should be made when suitable flutter-analysis methods are lacking, or when the results of flutter analyses are doubtful or indicate marginal stability. The tests should be performed at dynamic pressures up to 1.32 times the maximum expected flight dynamic pressure and throughout the Mach number range. Thermal effects should be considered in the model program—for example, by testing models with reduced stiffness to account for aerodynamic heating. Adequate dynamic simulation of the flight vehicle by the model should subsequently be verified by conducting influence-coefficient, structural-stiffness, and/or vibration tests on the full-scale vehicle. These tests should be performed on fully instrumented vehicles, in the flight configuration, having restraint or boundary conditions which simulate flight. Where analysis indicates critical aerothermoelastic effects, these tests should simulate the thermal environment by heating and cooling the test article in a manner which duplicates the most critical heating and cooling rates and temperatures to be encountered in flight. If it is determined that significant discrepancies exist between the model and flight vehicle, additional tests on suitably modified models should be performed.

It is recommended that the requirements of reference 6 for static and dynamic balance of control surfaces be satisfied. The requirements of reference 6 for allowable free play in control surfaces, as well as procedures for checking the free play, should also be met.

Wind-tunnel tests in the transonic speed range are recommended to demonstrate freedom from control-surface buzz when $b\omega/V < 0.3$, where b is the control-surface semichord in feet, ω is control-surface rotational frequency in radians per second, and V is free-stream velocity in feet per second. Such tests should be made on either dynamic models or full-scale components. Both Mach number and Reynolds number should be simulated in such tests. If buzz is present on a configuration, the buzz should be eliminated by increasing control-surface torsional or rotational rigidity, by the use of dampers, by the use of aerodynamic configurations which are not susceptible to buzz, or by combinations of these expedients.

Instrumentation for detecting flutter or buzz should be provided on at least one vehicle during development flight tests of new vehicles or of existing vehicles when configuration changes have been made involving elastic or inertial properties considered to adversely affect flutter characteristics. The instrumentation should be installed on vehicles that are to be programed to fly in regions of greatest dynamic pressure and in flight regions where the most severe heating is to be encountered.

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